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Technical Report 534

G. F. Dionne

Magnetic Moment Versus Temperature Curves of Rare-Earth Iron Garnets

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Prepared for the Department of the Army
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Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
LEXINGTON, MASSACHUSETTS

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MAGNETIC MOMENT VERSUS TEMPERATURE CURVES OF RARE-EARTH IRON GARNETS

G. F. DIONNE

Group 33

TECHNICAL REPORT 534

11 JULY 1979

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ABSTRACT

Molecular-field coefficients of the heavy rare-earth iron garnets (Tb, Dy, Ho, Er, Tm, and YbIG) have been determined by fitting calculated and experimental magnetic-moment-vs-temperature curves. For these compositions, spin canting appears to cause a significant reduction in the net moment of the c sublattice. The results are compared with values of coefficients derived from paramagnetic susceptibility measurements and with other values determined without taking into account c-sublattice canting. The capability of the computer program has been expanded to permit magnetization-temperature calculations of compositions that contain as many as three different rare earth ions in the c sublattice.

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CONTENTS

MAGNETIC MOMENT VERSUS TEMPERATURE CURVES OF RARE-EARTH IRON GARNETS

I. INTRODUCTION

The magnetic-moment-versus-temperature (n_B-vs-T) characteristics of rare-earth iron garnets have been important in microwave ferrite development and more recently in the emergence of ferrimagnetic thin-film technology for bubble memory devices. By determining molecular-field coefficients, the curves of these materials may be computed from the Néel theory,[1] and a basis may be established for predicting the curves of compositions with nonmagnetic ions substituted for Fe^{3+} or rare-earth irons.

In addition, it is also possible to compute curves for compositions containing more than one type of rare-earth ion. The purpose of this report is to present the results of investigations with a computer program that was used to determine the molecular-field coefficients and effective angular momentum quantum numbers of heavy rare-earth iron garnets.

II. THEORETICAL METHODS

In work reported previously, the molecular-field coefficients N_{ij} of $Y_3Fe_5O_{12}$ were determined by a trial-and-error procedure.[2-4] To arrive at a set of coefficients, N_{ij} were adjusted until the computed n_B-vs-T curves produced exact fits with the experimental curves for the same materials. For the above two materials, it was found that the octahedral (a) and tetrahedral (d) intrasublattice and intersublattice coefficients, N_{aa}, N_{dd}, and N_{ad}, originally determined for $Y_3Fe_5O_{12}$, were equally suitable for $Gd_3Fe_5O_{12}$. However, the effects of magnetic Gd^{3+} ions in the dodecahedral (c) sublattice were accounted for with values of N_{ac}, and N_{cd} listed in Table I. For the purpose of establishing a good fit to experimental results, it was convenient to assume that the small values of N_{cc} were negligible (see Fig. 1).

Since quenching of the orbital angular momentum is insignificant in the rare-earth family, the value of the spectroscopic splitting factor g_c is equal to the pure spin value of 2.0 only in the case of Gd^{3+} (an S-state ion). With every other ion, it is derived from the relation $g_c = (L_c + 2S_c)/[L_c + S_c]$ where L_c and S_c are the orbital and spin quantum numbers of the ground term, and should be combined with the total angular momentum J_c and the Bohr magneton μ_B in the Néel theory. In these cases, J_c replaces S_c and the magnetic moment per ion becomes $g_c \mu_B J_c$.

In Appendix A, the format for the modified Néel theory is presented for the general case with as many as three different c-sublattice rare-earth ions. Because the intrasublattice coefficients N_{cc} are negligible, it may be assumed that any rare-earth ion is coupled only to the iron in the a and d sublattices and does not interact any other rare-earth ion. In this way, it is possible to treat these cases as if separate c-sublattices existed for each type of rare-earth ion, with variables x, y, and z designating the respective fractions of the different rare-earth ions in the dodecahedral sites. A complete listing of the Fortran program (compatible with the IBM/370 computer) is given in Appendix B.

III. RESULTS OF CALCULATIONS

With a trial-and-error procedure identical to that used in the previous work, molecular-field coefficients N_{ac} and N_{cd} were determined for Tb, Dy, Ho, Er, Tm, and Yb iron garnets[5-8].

TABLE I

MOLECULAR-FIELD COEFFICIENTS OF RARE-EARTH IRON GARNETS

c-site ion	g_c	J_c	J'_c	ϕ (deg)	N_{ac} (moles/cm^3)	N_{cd} (moles/cm^3)	N_{ac}* (moles/cm^3)	N_{cd}* (moles/cm^3)	N_{ac}† (moles/cm^3)	N_{cd}† (moles/cm^3)
Gd^{3+}	2	3.5	3.50	0	−3.44	6.0	−1.2	3.4	–	–
Tb^{3+}	3/2	6.0	4.60	40.0	−4.5	6.5	−4.4	4.6	−1.80	3.40
Dy^{3+}	4/3	7.5	5.30	45.0	−5.2	6.0	−3.2	3.6	−3.35	3.95
Ho^{3+}	5/4	8.0	4.98	51.5	−1.5	4.0	−4.0	2.4	−0.75	1.50
Er^{3+}	6/5	7.5	4.62	52.0	−0.5	2.2	−0.6	1.0	−0.75	1.25
Tm^{3+}	7/6	6.0	1.085	79.6	−1.0	17.0	0	0	−1.00	8.00
Yb^{3+}	8/7	3.5	1.49	64.8	−6.0	8.0	−1.0	8.8	−1.70	2.00

*Data derived from paramagnetic susceptibility measurements of Aleonard (Ref. 11).

†Results reported by Brandle and Blank (Ref. 12).

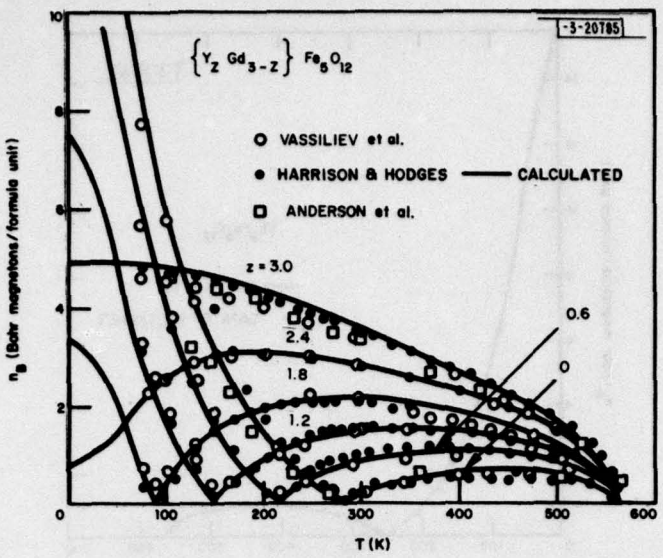

Fig. 1. Comparison between theory and experiment for n_B-vs-T curves of $Y_zGd_{3-z}Fe_5O_{12}$, using data of Vassiliev et al. (Ref. 13), Harrison and Hodges (Ref. 9), and Anderson et al. (Ref. 14).

Examples of the precision of the fits between calculated curves and experimental data points are given in Figs. 2 through 7. For these compositions, it was necessary to introduce an effective angular momentum $J_c' < J_c$ to produce an exact fit at T = 0 K. The values of J_c' required for this purpose are given in Table I, and suggest that a canting effect or departure from collinearity within the c sublattice likely accounts for the reduced c-sublattice moments. The extent of canting has been estimated by computing a canting angle ϕ, defined by the relation $J_c' = J_c \cos\phi$ (see Table I).

Because of the generally weak magnetic exchange coupling associated with c sublattices, this effect may be attributed to magnetocrystalline anisotropy. This argument is consistent with the fact that the correction of J_c for canting was not necessary with Gd^{3+}, the only ion of the group without an orbital contribution to J_c and the spin-orbit coupling energy required for a first-order anisotropy effect.

To demonstrate the program's capability with different rare-earth ions in the same composition, complete curves are presented in Fig. 8 for the system $Y_{2.7-x}Gd_xDy_{0.3}Fe_5O_{12}$ together with available experimental data,[9] and a comparison between theoretical and experimental compensation temperatures[10] for $Er_xGd_{3-x}Fe_5O_{12}$ is given in Fig. 9.

IV. DISCUSSION

In work reported by Aleonard,[11] molecular-field coefficients were determined for these compositions from paramagnetic susceptibility measurements above the Curie temperatures. Although these values (see Table I) could not be expected to produce accurate n_B-vs-T curves, it is interesting that their relative magnitudes agree at least qualitatively with those determined in this work.

More recent values of these coefficients have been reported by Brandle and Blank[12] and are also included in Table I for comparison. These values were determined in a manner similar to

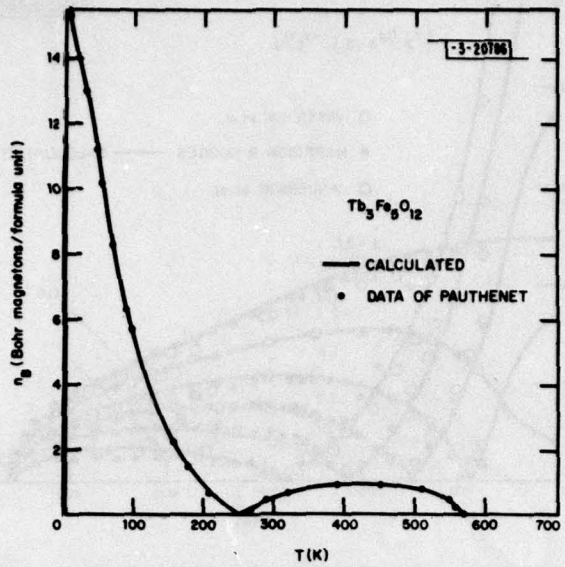

Fig. 2. Comparison between theory and experiment for the n_B-vs-T curve of $Tb_3Fe_5O_{12}$, using data of Pauthenet (Ref. 5).

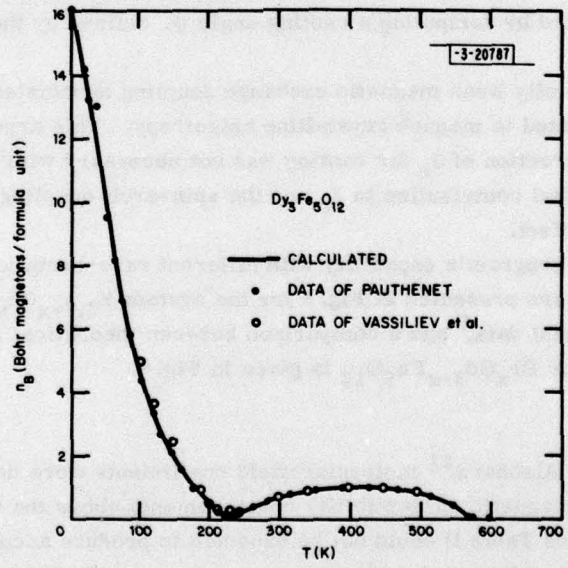

Fig. 3. Comparison between theory and experiment for the n_B-vs-T curve of $Dy_3Fe_5O_{12}$, using data of Pauthenet (Ref. 5) and Vassiliev et al. (Ref. 7).

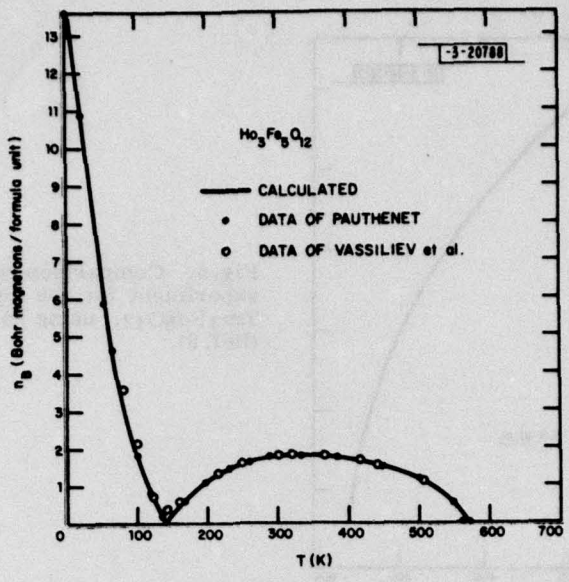

Fig. 4. Comparison between theory and experiment for the n_B-vs-T curve of $Ho_3Fe_5O_{12}$, using data of Pauthenet (Ref. 5) and Vassiliev et al. (Ref. 7).

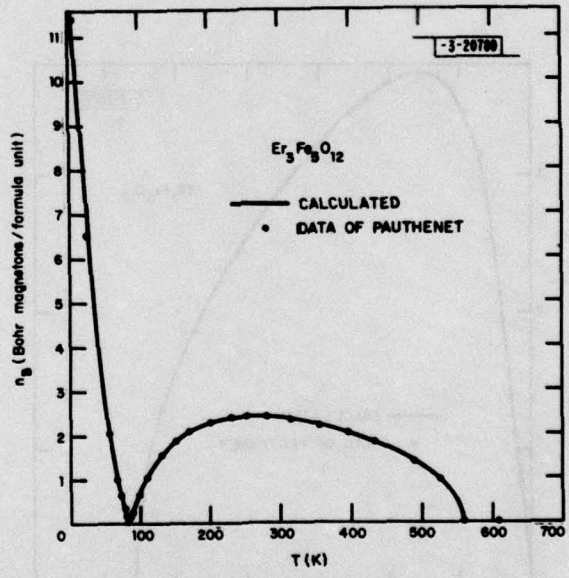

Fig. 5. Comparison between theory and experiment for the n_B-vs-T curve of $Er_3Fe_5O_{12}$, using data of Pauthenet (Ref. 5).

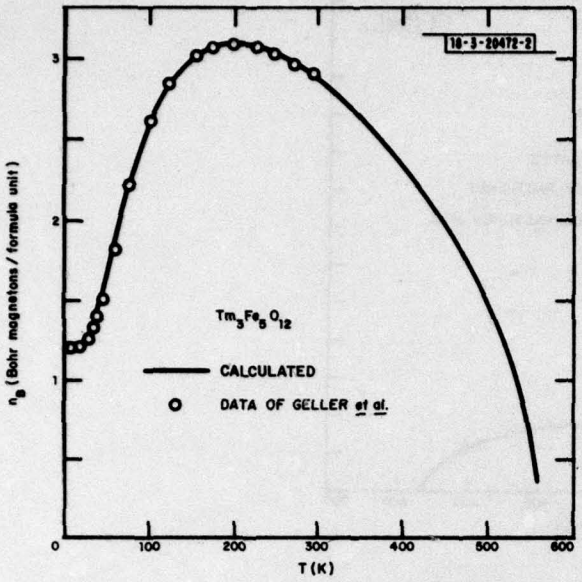

Fig. 6. Comparison between theory and experiment for the n_B-vs-T curve of $Tm_3Fe_5O_{12}$, using data of Geller et al. (Ref. 8).

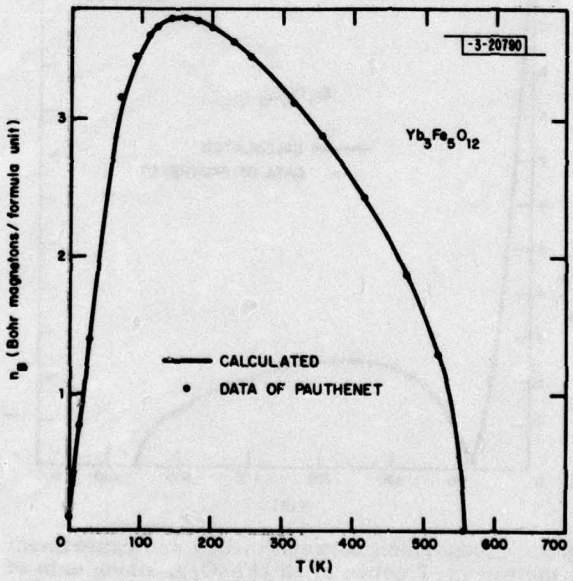

Fig. 7. Comparison between theory and experiment for the n_B-vs-T curve of $Yb_3Fe_5O_{12}$, using data of Pauthenet (Ref. 5).

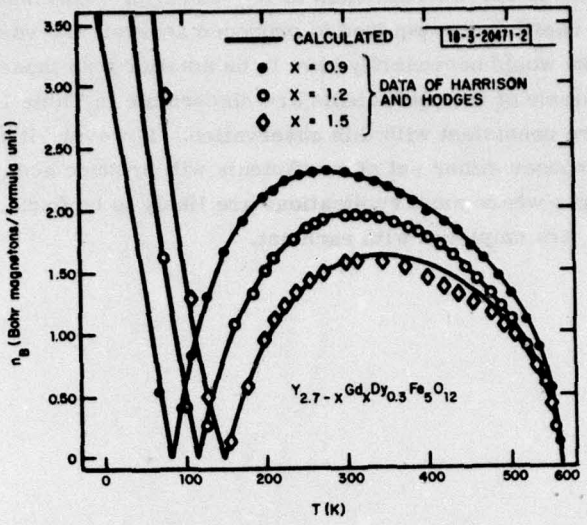

Fig. 8. Comparison between theory and experiment for n_B-vs-T curves of $Y_{2.7-x}Gd_xDy_{0.3}Fe_5O_{12}$, using data of Harrison and Hodges (Ref. 9).

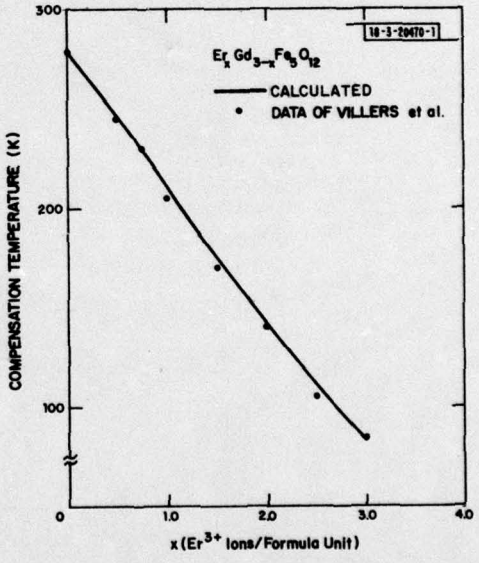

Fig. 9. Comparison between theory and experiment for compensation temperatures of $Er_xGd_{3-x}Fe_5O_{12}$, using data of Villers et al. (Ref. 10).

the procedure used here, but the work did not, in general, include a fit to the low-temperature points at T ~ 0 K. Consequently, the effect of canting was not taken into account and reduced values of J_c were not used in the determination of N_{ac} and N_{cd}. With these higher values of J_c, the molecular-field coefficients required to produced accurate n_B-vs-T curves over the higher temperature range would necessarily have to be smaller than those reported in this work. The differences in magnitude of the coefficients are discernible in Table I by inspection of the respective values and are consistent with this observation. However, it should also be pointed out that for practical purposes either set of coefficients will produce accurate fits over the higher temperature ranges where most applications are likely to be found, provided that the appropriate values of J_c are employed with each set.

ACKNOWLEDGMENT

The author is indebted to Dr. Paul F. Tumelty of Allied Chemical Corporation for helpful suggestions on the work reported, as well as Rodney Lewis and Susan Rajunas for composing the computer program listed in Appendix B.

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APPENDIX A

For the three sublattice case with as many as three different magnetic ions in the c sublattice, the Néel theory must be augmented as follows:

$$M = |M_d - M_a - M_{cx} - M_{cy} - M_{cz}| \quad , \tag{A-1}$$

where the subscripts d, a, and c refer to the tetrahedral, octahedral, and dodecahedral sublattices, and x, y, and z represent different c-sublattice magnetic ions. For each sublattice, $M_i(T) = M_i(0)\, B_{s_i}(x_i)$, with

$$x_d = \frac{S_d g_d \mu_B}{kT} (N_{dd}M_d + N_{ad}M_a + N_{cdx}M_{cx} + N_{cdy}M_{cy} + N_{cdz}M_{cz}) \quad ,$$

$$x_a = \frac{S_a g_a \mu_B}{kT} (N_{ad}M_d + N_{aa}M_a + N_{acx}M_{cx} + N_{acy}M_{cy} + N_{acz}M_{cz}) \quad ,$$

$$x_{cx} = \frac{J'_{cx} g_{cx} \mu_B}{kT} (N_{cdx}M_d + N_{acx}M_a + N_{ccx}M_{cx}) \quad ,$$

$$x_{cy} = J'_{cy} g_{cy} \mu_B (N_{cdy}M_d + N_{acy}M_a + N_{ccy}M_{cy}) \quad ,$$

$$x_{cz} = J'_{cz} g_{cz} \mu_B (N_{cdz}M_d + N_{acz}M_d + N_{ccz}M_{cz}) \quad , \tag{A-2}$$

where B_s is the Brillouin function, k is Boltzmann's constant, and μ_B is the Bohr Magneton. For practical purposes, it may be assumed that N_{ccx}, N_{ccy}, and $N_{ccz} \simeq 0$.

At T = 0 K, the magnetic moments per formula unit are given by

$$M_d(0) = 3 g_d S_d \mu_B N (1 - k_d)(1 - 0.1\, k_a) \quad ,$$

$$M_a(0) = 2 g_a S_a \mu_B N (1 - k_a)(1 - k_d^{5.4}) \quad ,$$

$$M_{cx}(0) = 3x g_{cx} J'_{cx} \mu_B N (1 - k_c) \quad ,$$

$$M_{cy}(0) = 3y g_{cy} J'_{cy} \mu_B N (1 - k_c) \quad ,$$

$$M_{cz}(0) = 3z g_{cz} J'_{cz} \mu_B N (1 - k_c) \quad ,$$

where N is Avogadro's number, and k_d, k_a, and k_c are the fractions of nonmagnetic ions in the respective sublattices, and x, y, and z represent the respective fractions of magnetic ions in the c sublattice (i.e., $x + y + z = 1$).

APPENDIX B
COMPUTER PROGRAM

```
FILE: DI3PUB2  FORTRAN  A    1/08/79 15:07    M.I.T. LINCOLN LABORATORY

C      MAIN PROGRAM FOR 3 MOMENTS-- USING SUBROUTINE MOM3 FOR CON-
C      VERGENCE.  G. DIONNE
       IMPLICIT REAL*8 (A-H,K,M,N,O-Z)
       REAL*8 JCPX,JCPY,JCPZ
       REAL*4 TT,YY
       COMMON /CM1/ SD,SA,JCPX,JCPY,JCPZ,MUB,K,BN,GD,GA,GCX,GCY,GCZ,X,Y,Z
       COMMON /CM2/ NDD,NAA,NAD,NACX,NACY,NACZ,NCDX,NCDY,NCDZ,NCCX,NCCY,
      1NCCZ
       COMMON /CM3/ KD,KA,KC
       COMMON /ANS/ M,MD1,MA1,MCX1,MCY1,MCZ1,NBANS
       DIMENSION TEMP(200),NB(200),KAA(21),KDD(21),NBB(21,200),MSAVE(21),
      1KCC(5)
C      THE FOLLOWING ARRAYS ARE USED IN PLOTTING ONLY
       DIMENSION TITLE(9),YY(1700),TT(1700),LC(21)
C      T1 AND T2 ARE LABELS FOR THE X AND Y AXES
       DATA T1/'TEMP'/,T2/'NB  '/
       DATA KCC/.8D0,.7D0,.6D0,.5D0,.4D0/
C      THE FOLLOWING TWO LINES REFER TO ROUTINES ACCESSIBLE TO USERS OF
C      LINCOLN'S 360/67 AND PERTAIN ONLY TO THE PLOTTING
       CALL TEKZZ(2)
C       CALL STOIDV(' G. DIONNE',9,0)
       CALL ENTERG('G. DIONNE',9)
       NGRAPH = 2
       SD=2.5
       SA=2.5
       MUB=9.27E-21
       K=1.38E-16
       BN=6.023E+23
       GD=2.0
       GA=2.0
       WRITE(6,208)
  208  FORMAT(' INPUT KA,KC,KD')
       READ(5,*) KA,KC,KD
       WRITE(6,209)
  209  FORMAT(' INPUT X,Y,Z')
       READ(5,*) X,Y,Z
       WRITE(6,210)
  210  FORMAT(' INPUT GCX,GCY,GCZ')
       READ(5,*) GCX,GCY,GCZ
       WRITE(6,212)
  212  FORMAT(' INPUT JCPX,JCPY,JCPZ')
       READ(5,*) JCPX,JCPY,JCPZ
       IF(Y.EQ.0.) JCPY = 2.
       IF(Z.EQ.0.) JCPZ = 2.
       IF(Y.EQ.0.) GCY = 2.
       IF(Z.EQ.0.) GCZ = 2.
       WRITE(6,211)
  211  FORMAT(' INPUT NACX,NACY,NACZ,NCDX,NCDY,NCDZ')
       READ(5,*) NACX,NACY,NACZ,NCDX,NCDY,NCDZ
       NCCY = 0.
       NCCZ = 0.
       NCCX = 0.
C      INITIAL KA VALUE
       KAA(1)=.00
C      INITIAL KD VALUE
```

```
      KDD(1)=.00
C     INCREMENT FOR KA AND KD
      DK=.01
C     INCREMENT FOR TEMPERATURE
      DT=10.
C     NUMBER OF CURVES PER PAGE (NUMBER OF KD'S USED)
      ICURVE=1
      DO 59 L=1,ICURVE
      KAA(L)=KAA(1)+(L-1)*DK
   59 KDD(L)=KDD(1)+(L-1)*DK
C     DO 218 LRR=1,5
C     KC=KCC(LRR)
C    CHANGED 1, 6 TO 1,1
      DO 100 LKA=1,1
C      KA=KAA(LKA)
C     THE FOLLOWING 3 LINES ARE RELEVANT ONLY TO THE PLOTTING
      IXZ=0
      NMAX=-25.E+25
      NMIN=25.E+25
      DO 200 LKD=1,ICURVE
C      KD=KDD(LKD)
      NDD=-30.4*(1.-.87*KA)
      NAA=-65.*(1.-1.26*KD)
      NAD=97.*(1.-.25*KA-.38*KD)
      TEMP(1)=0.0
      TEMP(2)=20.
      IF(KD.LT..10.OR.KA.LT..10.OR.KC.LT..10) TEMP(2)=40.
      IF(TEMP(2).EQ.40.) GO TO 21
      TEMP(29)=293.
      TEMP(35)=343.
      DO 31 L=2,28
   31 TEMP(L)=TEMP(2)+(L-2)*DT
      DO 32 L=30,34
   32 TEMP(L)=TEMP(28)+(L-29)*DT
      DO 33 L=36,72
   33 TEMP(L)=TEMP(34)+(L-35)*DT
      GO TO 22
   21 TEMP(28)=293.
      TEMP(34)=343.
      DO 34 L=2,27
   34 TEMP(L)=TEMP(2)+(L-2)*DT
      DO 35 L=29,33
   35 TEMP(L)=TEMP(27)+(L-28)*DT
      DO 36 L=35,72
   36 TEMP(L)=TEMP(33)+(L-34)*DT
   22 CALL MOM3
      M1=1.
      M2=-9999.
      DO 70 L=1,72
      T=TEMP(L)
      CALL CONTIN(T,ITER,IER)
      IF(IER.EQ.1) GO TO 150
      IF(TEMP(2).EQ.20..AND.L.EQ.29) M1=M
      IF(TEMP(2).EQ.20..AND.L.EQ.35) M2=M
      IF(TEMP(2).EQ.40..AND.L.EQ.28) M1=M
```

```
      IF(TEMP(2).EQ.40..AND.L.EQ.34) M2=M
      NBB(LKD,L)=NBANS
   70 CONTINUE
  150 IF(IER.EQ.1) LC(LKD)=L-1
      IF(IER.EQ.0) LC(LKD)=L
      MSAVE(LKD)=(M1-M2)/M1
      LE=LC(LKD)
C     THE FOLLOWING DO LOOP FORMS THE ARRAY OF ABSCISSAS FOR THE POINTS
C     TO BE PLOTTED
      DO 77 LA=1,LE
      IXZ=IXZ+1
      IF(TEMP(LA).EQ.150.) I150 = IXZ
   77 TT(IXZ)=TEMP(LA)
  200 CONTINUE
      WRITE(6,4) KC
    4 FORMAT(//' KC=',F5.2)
      WRITE(6,888)
      DO 98 LN=1,ICURVE
   98 WRITE(6,999) KA,KDD(LN),NBB(LN,1),TEMP(LC(LN)),MSAVE(LN)
  888 FORMAT(/10X,'KA',7X,'KD',7X,'NB AT TEMP=0',7X,'TEMP LIMIT',
     17X,'(M1-M2)/M1')
  999 FORMAT(8X,F5.3,4X,F5.3,8X,F8.3,10X,F8.3,7X,E12.5)
C     THE FOLLOWING DO LOOP FORMS THE ARRAY OF ORDINATES FOR THE POINTS
C     TO BE PLOTTED
      IN=0
      DO 61 LKD=1,ICURVE
      LP=LC(LKD)
      DO 61 LZ=1,LP
      IN=IN+1
      IF(LC(LKD).EQ.1) GO TO 61
      IF(NBB(LKD,LZ).GT.NMAX) NMAX=NBB(LKD,LZ)
      IF(NBB(LKD,LZ).LT.NMIN) NMIN=NBB(LKD,LZ)
   61 YY(IN)=NBB(LKD,LZ)
C     WRITE OUT VALUE OF NB AT 150 DEGREES
      WRITE(6,1001) YY(I150)
 1001 FORMAT(' NB AT 150 DEGREES = ',E13.6)
      CALL TEKERS(1)
      CALL PLOTLN(LE,TT,0.0,0.0,YY,0.0,0.0,0,'T(DEG. KELVIN)',14,
     1'NB',2,'MAGNETIC MOMENT',15,NGRAPH)
      CALL FILFRG(1)
  100 CONTINUE
  218 CONTINUE
C     THIS CALL SIGNALS THE END OF PLOTTING
   99 CALL EXIT
      STOP
      END
C     CALCULATION OF M VS TEMP FOR GARNETS WITH GD (+03)
      SUBROUTINE MOM3
      IMPLICIT REAL*8 (A-H,K,M,N,O-Z)
      REAL*8 JCPX,JCPY,JCPZ
      COMMON /CM1/ SD,SA,JCPX,JCPY,JCPZ,MUB,K,BN,GD,GA,GCX,GCY,GCZ,X,Y,Z
      COMMON /CM2/ NDD,NAA,NAD,NACX,NACY,NACZ,NCDX,NCDY,NCDZ,NCCX,NCCY,
     1NCCZ
      COMMON /CM3/ KD,KA,KC
      COMMON /ANS/ M,MD1,MA1,MCX1,MCY1,MCZ1,NB
```

```
      P=MUB*BN
      MDO=3.*GD*SD*P*(1.-KD)*(1.-.1*KA)
      MAO=2.*GA*SA*P*(1.-KA)*(1.-KD**(5.4))
      MCXO = 3.0*X*GCX*JCPX*P*(1.-KC)
      MCYO = 3.0*Y*GCY*JCPY*P*(1.-KC)
      MCZO = 3.0*Z*GCZ*JCPZ*P*(1.-KC)
      C1=1./(2.*SD)
      C2=(2.*SD+1.)*C1
      C3=1./(2.*SA)
      C4=(2.*SA+1.)*C3
      C5X = 1./(2.*JCPX)
      C5Y = 1./(2.*JCPY)
      C5Z = 1./(2.*JCPZ)
      C6X = (2.*JCPX+1.)*C5X
      C6Y = (2.*JCPY+1.)*C5Y
      C6Z = (2.*JCPZ+1.)*C5Z
      MD=MDO
      MA=MAO
      MCX=MCXO
      MCY=MCYO
      MCZ=MCZO
      MD1=MDO
      MA1=MAO
      MCX1=MCXO
      MCY1=MCYO
      MCZ1=MCZO
      RETURN
C*****************************************************************************
      ENTRY CONTIN(T,ITER,IER)
      ITER=0
      IER=0
      IF(T.EQ.0.0) M=DABS(MD-MA-MCX-MCY-MCZ)
      IF(T.EQ.0.0) GO TO 55
      FR = MUB/(K*T)
      IX=1
    9 ITER=ITER+1
      IF(ITER.GE.300) GO TO 999
       XD=GD*SD*FR*(NDD*MD+NAD*MA+NCDX*MCX+NCDY*MCY+NCDZ*MCZ)
      XA=GA*SA*FR*(NAA*MA+NAD*MD+NACX*MCX+NACY*MCY+NACZ*MCZ)
      XCX=GCX*JCPX*FR*(NCCX*MCX+NCDX*MD+
     1NACX*MA)
      XCY=GCY*JCPY*FR*(NCCY*MCY+NCDY*MD+
     1NACY*MA)
C       WRITE(6,*) GCZ,JCPZ,FR,NCCZ,MCZ,NCDZ,MD,NACZ,MA
      XCZ=GCZ*JCPZ*FR*(NCCZ*MCZ+
     1NCDZ*MD+NACZ*MA)
C       WRITE(6,*) XCZ
C       WRITE(6,*) XCZ
      BSD=C2*DCOSH(XD*C2)/DSINH(XD*C2)-C1*DCOSH(XD*C1)/DSINH(XD*C1)
      BSA=C4*DCOSH(XA*C4)/DSINH(XA*C4)-C3*DCOSH(XA*C3)/DSINH(XA*C3)
      IF(X.NE.0.0) BSCX=C6X*DCOSH(XCX*C6X)/DSINH(XCX*C6X)-C5X*DCOSH(XCX*
     1C5X)/DSINH(XCX*C5X)
      IF(Y.NE.0.0) BSCY=C6Y*DCOSH(XCY*C6Y)/DSINH(XCY*C6Y)-C5Y*DCOSH(XCY*
     1C5Y)/DSINH(XCY*C5Y)
      IF(Z.NE.0.0) BSCZ=C6Z*DCOSH(XCZ*C6Z)/DSINH(XCZ*C6Z)-C5Z*DCOSH(XCZ*
```

```
     1C5Z)/DSINH(XCZ*C5Z)
      IF(X.EQ.0.0)  BSCX = 0.0
      IF(Y.EQ.0.0)  BSCY = 0.0
      IF(Z.EQ.0.0)  BSCZ = 0.0
      MD2=MDO*BSD
      MA2=MAO*BSA
      MCX2=MCXO*BSCX
      MCY2=MCYO*BSCY
      MCZ2=MCZO*BSCZ
      GO TO (13,14),IX
   13 IX=2
      MD1=MD
      MA1=MA2
      MCX1=MCX2
      MCY1=MCY2
      MCZ1=MCZ2
      GO TO 15
   14 IX=1
      MD1=MD2
      MA1=MA
      MCX1=MCX2
      MCY1=MCY2
      MCZ1=MCZ2
   15 IF((DABS(MA1-MA).LT..0001.AND.DABS(MD1-MD).LT..0001)
     1.AND.(DABS(MCX1-MCX).LT..0001.AND.(DABS(MCY1-MCY).LT..0001.AND.
     1DABS(MCZ1-MCZ).LT..0001)))GOTO 8
      MD=MD1
      MA=MA1
      MCX=MCX1
      MCY=MCY1
      MCZ=MCZ1
      IF(MD.LT.0.0.OR.MA.LT.0.0.OR.MCX.LT.0.0.OR.MCY.LT.0.0.OR.MCZ.LT.0.
     1)GOTO 999
      GO TO 9
    8 M=DABS(MD-MA-MCX-MCY-MCZ)
   55 NB=M/(MUB*BN)
      GO TO 888
  999 IER=1
  888 RETURN
      END
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REPORT DOCUMENTATION PAGE

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Molecular-field coefficients of the heavy rare-earth iron garnets (Tb, Dy, Ho, Er, Tm, and YbIG) have been determined by fitting calculated and experimental magnetic-moment-vs-temperature curves. For these compositions, spin canting appears to cause a significant reduction in the net moment of the c sublattice. The results are compared with values of coefficients derived from paramagnetic susceptibility measurements and with other values determined without taking into account c-sublattice canting. The capability of the computer program has been expanded to permit magnetization-temperature calculations of compositions that contain as many as three different rare earth ions in the c sublattice.

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SUPPLEMENTARY

INFORMATION

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ERRATA SHEET

for

TECHNICAL REPORT 534

The author of Technical Report 534 (G. F. Dionne, "Magnetic Moment versus Temperature Curves of Ferrimagnetic Garnet Materials," 11 July 1979) has discovered that incorrect values of the parameter N_{ac} were presented in Table I (page 2). The revised Table I contains the correct values, and should replace the original Table I.

On line 6 of page 11, a more precise definition of the Brillouin function $B_{s_i}(x_i)$ is $B_{J'_i}(x_i)$, where $J'_a = S_a$ and $J'_d = S_d$.

27 July 1981

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TABLE I

MOLECULAR-FIELD COEFFICIENTS OF RARE-EARTH IRON GARNETS

c-site ion	g_c	J_c	J'_c	ϕ (deg)	N_{ac} (moles/cm^3)	N_{cd} (moles/cm^3)	N_{ac}* (moles/cm^3)	N_{cd}* (moles/cm^3)	N_{ac}† (moles/cm^3)	N_{cd}† (moles/cm^3)
Gd^{3+}	2	3.5	3.50	0	−3.44	6.0	−1.2	3.4	–	–
Tb^{3+}	3/2	6.0	4.60	40.0	−4.2	6.5	−4.4	4.6	−1.80	3.40
Dy^{3+}	4/3	7.5	5.30	45.0	−4.0	6.0	−3.2	3.6	−3.35	3.95
Ho^{3+}	5/4	8.0	4.98	51.5	−2.1	4.0	−4.0	2.4	−0.75	1.50
Er^{3+}	6/5	7.5	4.62	52.0	−0.2	2.2	−0.6	1.0	−0.75	1.25
Tm^{3+}	7/6	6.0	1.085	79.6	−1.0	17.0	0	0	−1.00	8.00
Yb^{3+}	8/7	3.5	1.49	64.8	−4.0	8.0	−1.0	8.8	−1.70	2.00

*Data derived from paramagnetic susceptibility measurements of Aleonard (Ref. 11).

†Results reported by Brandle and Blank (Ref. 12).